Thirty-five-gigahertz measurements of CO_2 crystals

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[1]   In order to learn more about the Martian polar caps, it is important to compare and contrast the behavior of both frozen H_2O and CO_2 in different parts of the electromagnetic spectrum. Because relatively little attention has been given, thus far, to observing the seasonal Martian polar caps in the thermal microwave part of the spectrum, in this experiment, a 35-GHz handheld radiometer was used to measure the microwave emission and scattering from layers of manufactured CO_2 (dry ice). Compared to natural snow crystals, results for the dry ice layers exhibit lower microwave brightness temperatures for similar thicknesses, regardless of the incidence angle of the radiometer. For example, at 50° H (horizontal polarization) and with a covering 18 cm of dry ice, the brightness temperature was 76 K. When the total thickness of the dry ice was 27 cm, the brightness temperature was 86 K. The lower brightness temperatures are due to a combination of the lower physical temperature and the larger crystal sizes of the commercial CO_2 crystals compared to the snow crystals. While little is known about the CO_2 and water snowpacks on Mars, it is likely that the particles are in close contact with one another as is the case for ice sheets on Earth – the grains are interconnected. This would qualify as a dense media. In densely packed media, the particles do not scatter independently; rather, they interact with other particles. Dense media calculations compare very favorably with the observed values from the handheld radiometer. The calculated versus observed TBs are within 10% for each case with the exception of the 26 cm layer thickness and the 0.8 mm particle size (15%) and for the 14 cm layer thickness and the 2.0 mm particle size (16%). Thus, it appears that dense media transfer modeling (DMRT) will be useful for modeling the flow of energy emerging from frozen CO_2 deposits. Because the dry ice used in this experiment was manufactured in the shape of cylindrical pellets, an effort was made to see what effect, if any, the shape of the crystal, for different particle sizes, has on microwave scattering. Results from a discrete dipole scattering (DDSCAT) model show that differently shaped crystals, having the same effective radius of a sphere, give very similar cross section/efficiencies.   INDEX TERMS: 5462 Planetology: Solid Surface Planets: Polar regions; 1863 Hydrology: Snow and ice (1827); 3349 Meteorology and Atmospheric Dynamics: Polar meteorology; 3346 Meteorology and Atmospheric Dynamics: Planetary meteorology (5445, 5739); KEYWORDS: remote sensing, climate, Mars, microwave, snow, carbon dioxide

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1.   Introduction

[2]   The microwave region contributes little to the total radiation budget of Earth or Mars, compared to the ultraviolet, visible and infrared wavelengths. However, because ice crystals appreciably scatter and absorb (depending on the crystal size) upwelling microwave radiation emanating from the Earth at frequencies above about 10 GHz, microwave radiometry offers the potential to assess the thickness and the extent of the Martian

seasonal caps using remote sensing techniques. In terms of remotely sensing the Martian seasonal and permanent ice caps, relatively little attention has been thus far given to observing the thermal microwave part of the spectrum. An advantage of using this approach is that microwaves are indifferent to daylight and darkness. Therefore, the thickness and extent of the caps can be estimated even during the polar night period. [*Foster et al.*, 1998]. This 1998 paper laid the groundwork for the present study.

[3] Although much of what is known about the composition and structure of the Martian polar caps is a result of laboratory work and modeling, in the microwave region of the spectrum, there is a need to conduct basic experiments related to how microwaves are scattered and or absorbed by accumulations of CO$_2$ crystals having various sizes. A problem, of course, with experimental measurements, is how to make them under conditions, which are analogous to the conditions expected on Mars. Otherwise, the results may not fully explain what is observable on Mars. Nonetheless, initial experiments with preliminary findings are useful for helping to design further experiments and to validate modeling results.

[4] The purpose of this paper is to measure the passive microwave brightness temperatures of frozen CO$_2$ (dry ice) at 35 GHz (~0.8 cm), using a handheld radiometer. The CO$_2$ brightness temperatures will be modeled using dense media radiative transfer theory and compared to the radiometric observations. A discrete dipole scattering model will be employed to assess what affect the shape of the CO$_2$ crystal, for a range of particle sizes, has on microwave scattering. Unfortunately, there are no direct (in situ) Viking Lander measurements of the Martian polar caps, and there are few orbital measurements (either from the Mariner, Mars, Phobos or even Pathfinder missions), that can be used as a standard of reference for comparison with the laboratory measurements of CO$_2$ crystals and the modeling results on CO$_2$ extinction efficiency described in this paper. However, the measured response from dry ice can be compared with the modeled results to assess whether or not the model can be used to accurately gage the extinction of CO$_2$ and H$_2$O crystals having different sizes.

5. Conclusions and Future Plans

[47] In this study it was found that compared to natural snow crystals, the dry ice crystals exhibited lower brightness temperatures. This is attributed to both the greater scattering of the larger pellets of CO$_2$, which are about an order in magnitude larger than the largest snow crystals, and the colder physical temperatures of the dry ice. For instance, a brightness temperature of only 86 K was measured over the aluminum plate when the thickness of the dry ice was 27 cm, for an incidence angle of 50 degrees (horizontal polarization).

[48] Dense media calculations compare very favorably with the observed values from the handheld radiometer. The observed versus calculated TBs are within 10% for each case with the exception of the 26 cm layer thickness and the 0.8 mm particle size (15%) and for the 14 cm layer thickness and the 2.0 mm particle size (16%). Thus, it appears that DMRT will be useful for modeling the flow of energy emerging from frozen CO$_2$ deposits.

[49] From the DDSCAT model calculations, it can be seen that differently shaped crystals, having the same effective radius of a sphere, give very similar cross section/efficiencies. However, for the CO$_2$ crystals, for sizes 1,000 μm or smaller, tetrahedron shapes scatter slightly more than cylinders, while for sizes larger than 1,000 μm, the reverse is true. For water crystals, the tetrahedron shapes also scatter minutely more than do cylinders [*Foster et al.*, 1998].

[50] Eventually, we would like to be able to construct an artificial CO$_2$ snowpack having larger crystals at the bottom and smaller crystals at the surface. It would be useful to measure crystals of various sizes with the 35-GHz handheld radiometer and, in addition, to use another radiometer tuned to a higher (85 GHz) frequency.